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A Review of Solar Panel Cooling Methods and Efficiencies

Aljumaili A.[1], Alaiwi Y.[1], Al-Khafaji Z.[2,3] *
[1]Altinbas University, Instambul, Turkey
[2]Imam Ja'afar Al-Sadiq University, Baghdad, Iraq
[3]Universiti Kebangsaan Malaysia, Bangi, Malayisa
*corresponding authors

Abstract: Photovoltaics is one of the most widely employed clean energy sources on earth. However, when the temperature of the PV cell rises, its electrical power decreases, which makes it essential to find ways to develop the module's efficiency in high-temperature situations. One of the techniques used to raise efficiency and performance is cooling. Researchers have used a variety of ways to cool solar PV panels, including active and passive methods. Researchers used a forced air stream, PCM, a heat exchanger, water, and many other methods to make a solar PV thermal system work better. The principal purpose of this chapter is to look at the significant information the researchers found in their research about how to improve the efficiency and performance of PV cells, how to cool them, and other reasons that affect the output of solar cells.

Keywords: solar panel; cooling methods; cooling efficiencies.

Introduction

Clean energy refers to energy sources that regenerate spontaneously and may be utilized repeatedly [1], [2], [3]. Some energy sources are solar, wind, geothermal, hydropower, and bioenergy. In general, renewable energy sources are seen as more ecologically responsible and sustainable than non-renewable power sources, such as fossil fuels, which are limited and emit greenhouse gases when burned [4]. The use of renewable energy sources has several advantages. For instance, they can lessen our dependence on fossil fuels, which is significant in climate change [5], [6], [7], [8], [9].

Additionally, renewable energy sources can offer a more consistent and predictable energy supply and often have lower long-term operational expenses. Additionally, renewable energy may foster employment growth and local economic development [10]. Although the UN globalist agenda emphasized the necessity of developing green power and lowering pollution (CO_2 or NOx), facts indicate that these targets are not achievable under the existing structure. If global coal and natural gas usage continues at its present rate, the heat of the earth is expected to increase by 4–6 °C above what it was before industrialization.

A rise of this magnitude would be disastrous for food production, people's health, and biodiversity. It would jeopardize the existence of communities in so many places on the globe [11]. Solar energy has the potential to fulfill the world's energy needs if it is exploited efficiently. Energy from the sun can be converted directly to electricity by photovoltaic cells (PV) or converted thermally by concentrated solar power. PV technology has become more attractive in recent years thanks to a considerable cost reduction. Solar energy system operating costs are frequently cheaper than non-renewable energy sources. However, PV cells cannot convert all of the energy in the solar spectrum due to their inability to utilize low-energy photons and the thermal energy produced through thermalization by high-energy photons [12], [13], [14], [15], [16].

The sun produces enormous amounts of energy, and the planet receives about 1.8 x 1014 kW daily, which accounts for a significant fraction of the sun's total solar power, calculated to be 3.8 x 1023 kW. Solar energy is a renewable resource that may power various devices, such as solar water heaters, concentrated solar power plants, and solar panels [17].

The two crucial factors that affected a solar photovoltaic company's effectiveness were the dispersion and intensity of solar radiation. The two factors differ significantly across countries. Asia has the highest potential for solar radiation absorption compared to other warm countries since their year-round sunshine duration is more significant. Fig. (1) shows the variation of solar radiation in the Middle East. Understanding that much solar energy is wasted since it is unused [18] is essential. Using semiconducting materials that show the photovoltaic effect, the process known as photovoltaic (PV) transforms light into electricity. When photons (light particles) from the sun or other light sources dislodge electrons from their atoms, a current of electricity is produced. Typically constructed of silicon, PV cells are organized in panels or modules that may be put on buildings such as walls or roofs. Since it has been around for a while, photovoltaic PV technology has become famous for power in homes, companies, and other purposes [19]. As shown in Fig. 2.

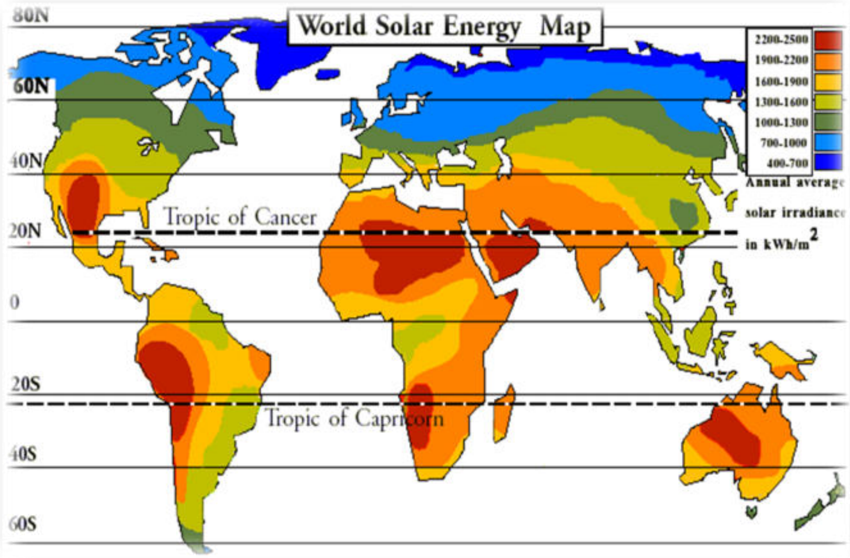

Fig. 1. - Solar radiation [20]

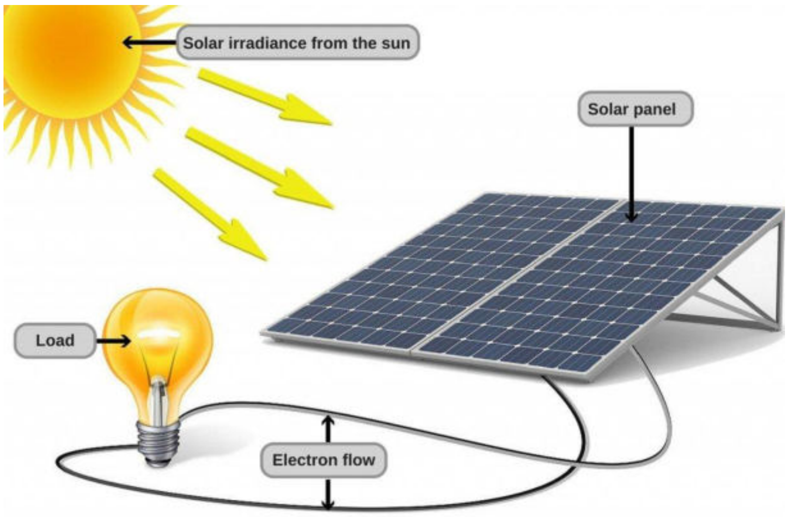

Fig. 2. - Converting sunlight into electricity [21]

PV modules are quite sensitive to rising ambient temperatures. The power and performance of PV modules are reduced when the ambient temperature rises [22]. Solar cell power output P and voltage output V are connected through the P–V characteristic, assuming constant solar irradiance (E) and panel temperature (Tm). If Tm or E are modified in any way, the entire collection of attributes is modified. Fig. 3 shows a temperature increase in a cell. The maximum current of solar cells decreases as the temperature increases. For every 1 degree Celsius increase, the output power of the cells drops by 0.5%, which means that overheating can significantly impact the production of solar cells [23].

Solar PV cells are the primary element of PV systems and are mainly semiconductor devices that can convert solar radiation into DC electricity when exposed to sunlight. Such an optical cell consists of a P-N junction formed on a thin light-sensitive material, primarily silicon. The P-N junction of the cell is formed by doping a silicon wafer with impurities, thereby creating two layers with different electrical properties. The physical process through which solar cells convert solar radiation into electricity is known as the PV effect [24] to demonstrate the science of transforming the absorbed light from the silicon cell into a current.

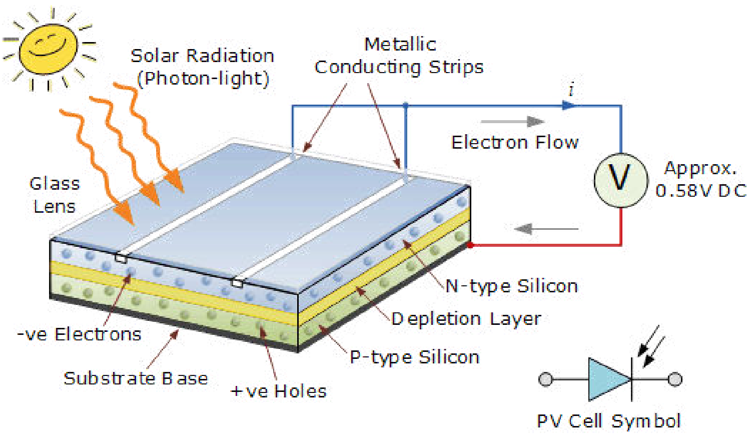

Fig. 3. - P-N junction for solar cell [25]

A typical PV panel has glass, silica, EVA, and PVF layers—Fig. 4. Predicting the amount of heat absorbed by photovoltaic cells can be difficult due to the varying absorptivity coefficients of various materials. The heat output of photovoltaic cells is complex and challenging to accurately determine due to factors such as cell efficiency, the environment in which the cells are used, and the material of the cells. Among other things, it impacts the temperature of the cells. Of day, the tilt angle, and a material's emissivity and reflectivity. The emissivity determines the amount of heat lost to the surrounding environment, but reflectivity determines how much heat is absorbed from the backside and frame of the model. The temperature of photovoltaics is generally higher than the ambient air temperature, leading to greater dissipation through heat loss rather than absorption through diffuse irradiance. Fig. 5 [26].

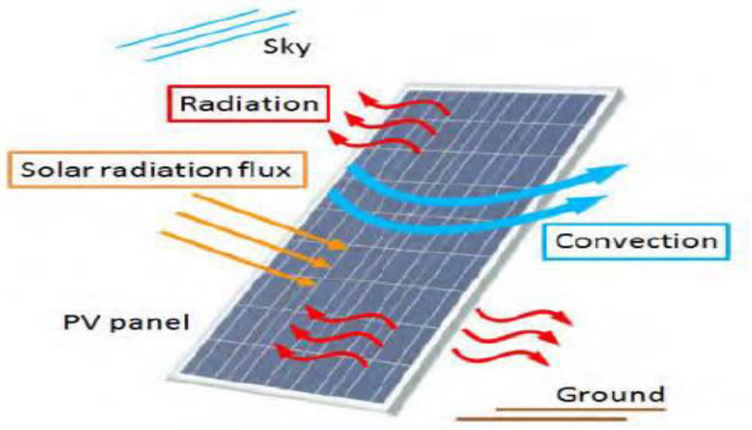

Fig. 4. - Heat transfer in PV panel [27]

Recently, the efficiency of photovoltaic panels has significantly improved, with some reaching more than 16%. However, panels with an efficiency rate of 11.7 percent are still widely available and have been shown to experience a decline in performance when their cell temperatures reach 25 °C [28].

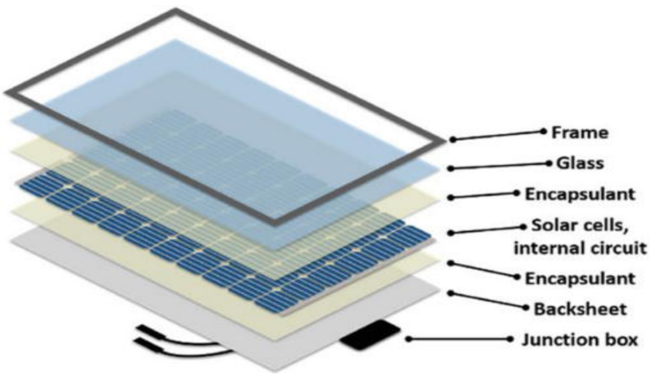

Fig. 5. - PV panel structures [29]

1. Phase Change Materials (PCM)

In recent years, PCM has been used in various applications, the most significant of which is cooling applications that utilize water and air because of their capacity to store enormous amounts of heat and dissipate it through melting, despite their small size. While it comes in various shapes and sizes, its primary applications include energy conservation in buildings and heat storage applications such as hot water tanks and protecting food from extreme heat during shipping and storage. Finally, it was used in photovoltaic (PV-PCM) applications to raise the efficiency of solar panels, an area in which researchers have made tremendous progress, and the rise in panel efficiency was noticed when phase-changing materials were used [30].

Phase change materials are categorized into two fundamental types of organic materials: paraffin compounds (amino acids) and non-paraffin compounds, which have high thermal stability and are employed in low-temperature applications. Inorganic materials, like salt hydrates, are more common than their predecessors. It is for use in low and moderate-temperature settings. The usage of (PCM) in house heating and cooling applications has been investigated. PCMs are adaptable, melting and solidifying across a wide temperature range, making them appropriate for various applications. Furthermore, such technologies benefit people and save energy, as shown in Fig. 6.

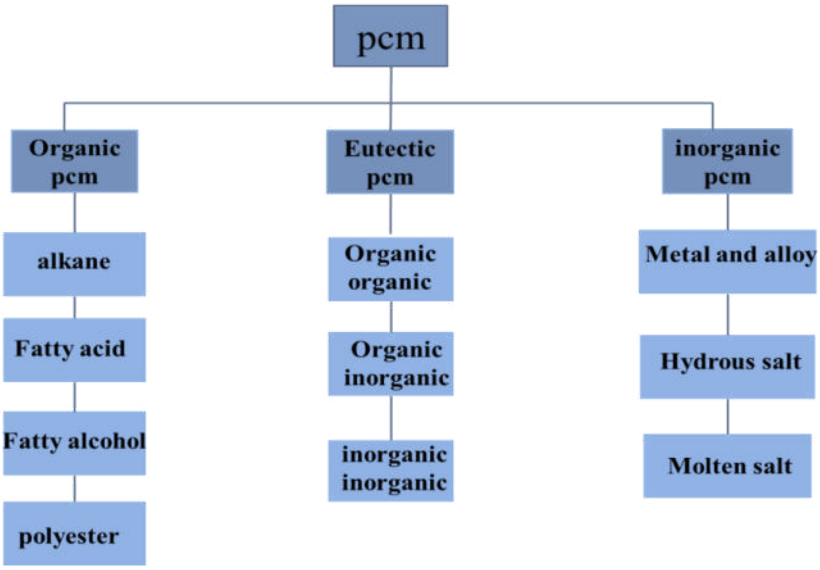

Fig. 6. - PCMs are classified according to their properties

Table 1. Type of Commercial PCM [31]

Organic	Commercial PCM
Paraffin c 18	S27
Tetradecanol	RT30
Paraffin c 16-28	TH29
Paraffin c 13	RT25
Dodecanol	STL27
Paraffin wax	RT40- RT50-RT58

PCMs are utilized for temperature regulation in several photovoltaic systems to decrease temperature-dependent photovoltaic efficiency loss. At three different degrees of insolation, the performance of each PCM was determined by evaluating four distinct PV/PCM systems. Modifying the mass and thermal conductivity of PCM was essential for adjusting PV temperature. The highest temperature drop of 18 degrees Celsius was obtained in 30 minutes, and a temperature drop of 10 degrees Celsius was maintained continuously for 5 hours [32].

A PV/PCM hybrid with two types of PCMs has been studied, and it can keep the PV at its average working temperature of 25°C, improving solar energy conversion efficiency during varying diurnal insolation. The incoming energy is captured as heat by the photovoltaic and transferred to the PCMs via the high thermal cell wall. The PCMs' thermal management properties may keep the PV temperature lower for longer [33]. (PCM) have been studied as a way to regulate the temperature of solar panels. By incorporating PCMs into the design of solar panels, it is possible to keep the cells' temperature closer to the ambient temperature for longer periods of time when exposed to high levels of solar radiation. For example, research has shown that using PCMs can allow solar panels to maintain a temperature below 40 degrees Celsius for an additional 80 minutes when subjected to 1000 W/m2 of solar radiation over a prolonged period [34].

Investigated on a global scale, the yearly growth in energy production provided by a photovoltaic structure with a phase change material core. PCM functions as a heatsink. The PCM provides cooling effects in regions with slight intra-annual climatic fluctuation. When the ideal PCM melting point is used, yearly photovoltaic energy production increases by more than 6% in Mexico and eastern Africa and more than 5% in several other regions [35]. The study specifically aimed at the thermal characteristics of three separate PCM classes. The thermophysical characteristics of five solid-liquid phase transition materials were analyzed for usage in photovoltaic heat regulation applications. The components were separated into three major categories: wax, salt hydrates, and fatty acid mixtures. It is essential to examine the link between the thermophysical characteristics of PCMs and their usage as temperature managers and the external operation of PV systems [36].

The photovoltaic panel's comprehensive heat transport analysis was done with the PCM. This study determined the convection influences on the melted PCM, the wind velocity, and the PV board's slope angle. Then noted, the panel's maximum working temperature when conduction and convection effects are combined is 54.90 °C, as well as 58.5 °C when convection in melted PCM is not included (just conduction mode). Additionally, higher wind velocity or a higher tilt angle have been shown to minimize the functioning temperature of PV panels [37].

The impact of adding phase-changing materials on power conversion efficiency and increased lifetime in building-integrated photovoltaics was examined. The primary purpose is to assess the operating temperature regulation for BIPV with and without PCMs under different climate conditions. The finding showed that PCM applications have a beneficial environmental effect because they use fewer resources to make BIPV. PCMs can store heat and avoid significant damage to the BIPV early in its life cycle [38]. The computational analysis and scientific experiment demonstrate that PCM can regulate the temperature of the PV model by ten degrees Celsius for around six hours in Malaysian conditions, as shown in Fig. 7. These temperature decreases greatly enhance the productivity of the photovoltaic module [39].

The efficiency of solar panels was investigated by utilizing a variety of cooling configurations that included a variety of thermal absorber designs, coolants, and PCMs. According to this study, PV panels incorporating PCM are effective options for solar panel cooling [40]. After significant research on several natural and forced cooling methods for solar photovoltaics, previously employed systems have been deemed superior. Inactive cooling uses PCM paraffins such as wax, eutectics, natural material, and cotton wick, whereas active cooling uses gas, water, and nanofluids. Then, it has been noticed that the ambient temperature of the panel affects the conversion process, which affects both electrical performance and efficiency. As the cell's temperature rises, its performance degrades [41].

Fig. 7. - Melted PCM pouring on the rear part of PV [39]

The thermodynamic photovoltaic-PCM model was investigated to determine a PCM's mass, heat, and energy transfer mechanisms under a photovoltaic panel. The appropriate PCM increases the created output energy to 12.7 W. The highest functional temperature of the photovoltaic cell was lowered from 70.36 °C to 56 °C because the PCM's thickness increased from 1 cm to 3 cm [42]. To create a simplified model to calculate and analyze both the effectiveness and thermal functionality of the PCM system, they examined different PCMs' melting points and latent temperatures to select the appropriate PCM and, based on previous reviews, then discovered that the plate temperature decreased by about 10.1 °C and the efficiency increased by up to 3.73 percent [30].

PCM was applied to the backside of a photovoltaic panel. PV thermal management (PCM) is designed to absorb the PV panel's excess heat, allowing for PV thermal control and energy power efficiency enhancement. The findings show that the PV temperature differential between photovoltaic systems without PCM and PV-PCM systems can reach 23 degrees Celsius, resulting in a 5.18 percent increase in the PV-PCM system's energy production [43]. To create a model to evaluate the PCM's functionality throughout the year and under different situations. Five modules were simulated, and the findings suggest that PCM performs well in the summer with a high melting point [44]. PCM is used as a cooling technique to improve the effectiveness of photovoltaic panels.

The influence of PCM physical properties, ambient conditions, and encapsulation design has been computed and empirically investigated. It can be demonstrated that using a suitable PCM can enhance the productivity of photovoltaic panels and PV thermal systems.

Then, PCM decreased the solar plate's heat and enhanced the structure's ability to convert solar energy into usable power [45]. An analytical and experimental investigation was undertaken to calculate the impact of inclination angles on the solution's efficacy—procedure properties of a substance (PCM) when used as a heatsink behind a solar panel. Based on the data, when the angle of tilt went from 0 to 90 degrees, the melting time went down, and the plate temperature went down by 0.4% to 12.0% [46]. Then, methods for cooling a solar panel with PCM on the backside of the PV model were investigated. They discovered that free cooling is more effective in hot conditions [47].

2. Heatsink

Heat sinks are used to passively or actively cool a method, with or without the expenditure of other power. Heatsinks are constructed of heat-absorbing and heat-distributing materials. Because of their excellent thermal conductivity, copper and aluminum are often used in heatsinks. Heatsinks use variously sized and shaped fins to dissipate heat [48]. The dispersants were employed in conjunction with solar cells and considerably lowered the panel's temperature, as the dispersants aid in heat dispersion to the surrounding region. Fig. 8 shows one type of heatsink and its operation [49].

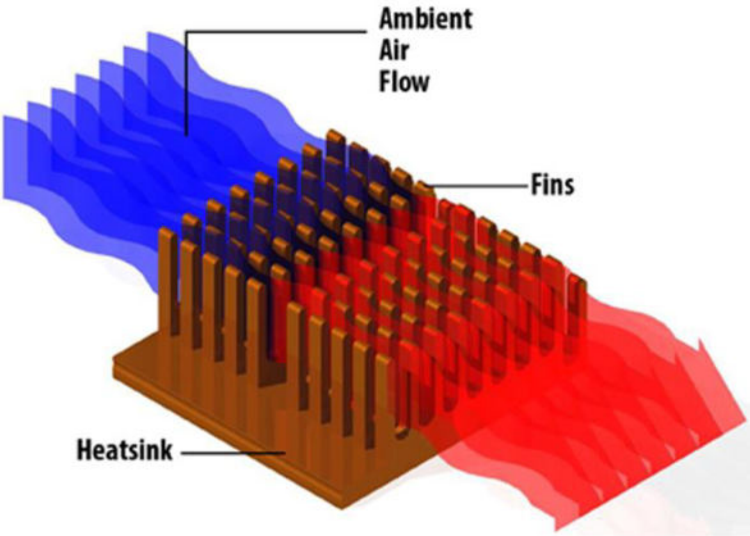

Fig. 8. - Heat sink

Researchers were able to study the impacts of four alternative thermal management methods on the thermal efficiency, point-based efficiency, and overall efficiency of a solar panel by mixing experimentally injected graphite with an externally finned heatsink. According to the findings of this study, this strategy was the most efficient way to improve the capacity of a solar panel by 12.97%. As a result, including graphite and an externally finned heatsink in the design of solar panels may be an efficient strategy to increase their performance and efficiency [50]. The effectiveness of a solar cell coupled to a thermal sink cooling system was evaluated under varying levels of solar radiation as well as passive and active air cooling over the heatsink. As compared to a solar cell cooled by natural convection, the temperature of a solar panel dropped by convective heat transfer at 500 W/m2 of incoming heat flux increased as the solar irradiation increased. 5.4% of the solar panel heat is dissipated when the heatsink is cooled by natural convection. In comparison, 11% is dissipated when cooled by forced convection because forced airflow has a higher heat transfer coefficient than natural airflow [19].

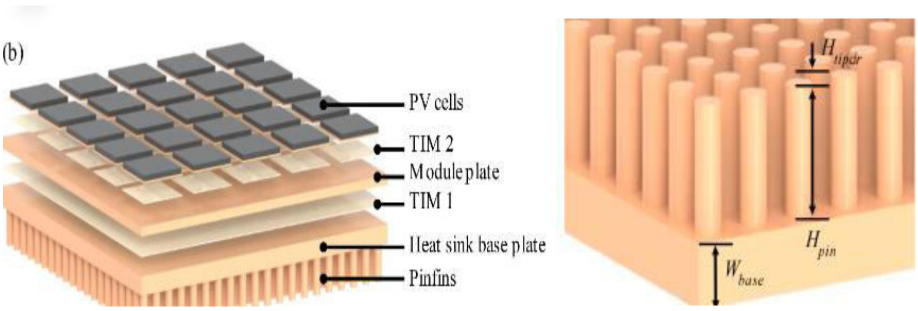

Fig. 9. - Heat sink with pin fins [51]

Looked for a link between lowering the heat of a cell and variations in its performance and productivity in cells during normal operation circumstances and those with thermoelectric panels. According to the findings, the combination of a heat sink and a thermoelectric module lowers the heat of the PV panels, increasing their efficiency as well as output power. The cooling performance was optimum. In an ideal situation, the thermoelectric heat transfer cells could increase solar panel performance and power output by 10.50% [52].

In an effort to design a more effective method for cooling the cell, they evaluated the output of a PV cell using a finned mini-channel heat sink exposed to a high concentration ratio. Introducing alumina and silicon dioxide nanoparticles improved the thermal conductivity of water. Furthermore, there was a substantial improvement when the fluid's temperature was increased. At a Re of 8.25 and a concentration level of 500, the system's overall efficiency improved by 3.82 percent [53].

Thermal control is achieved through the use of two layers of heat sink and a CPV cell. The cooling orientations of air in parallel flow and counter flow were examined. When the concentration ratio (CR) was 5, 10, 15, and 20, ethanol was used as a coolant to prevent the CPV from overheating. According to the experiments, temperatures drop significantly when the inlet flow rate is raised [54]. According to the research, a heat sink was used to cool a solar panel. Two Nanofluids cooled the heat sink. The heat sink comprises an aluminum cover and two zigzag-channeled components.

The heat sink and PV performance were evaluated for nanoparticle concentration at various Reynolds numbers. The introduction of alumina nanoparticles improves the thermal performance of solar cells. Increasing the (Re) number from 50 to 150 resulted in a 7% increase in thermal efficiency [55]. Analyzed cooling a solar cell module by increasing the back surface's heat transfer factor. The efficiency of a heat sink engaged on the backside of a panel is studied, as is the impact of fin height on heatsink performance. The panel's front and back surfaces achieved 62 °C and 51 °C, respectively, with a 20 mm heatsink fin height. When the fins were 300 mm long, temperatures dropped to 45 °C as well as 30 °C, respectively. Fig. 10 shows a heatsink with a fin length of 20 mm.

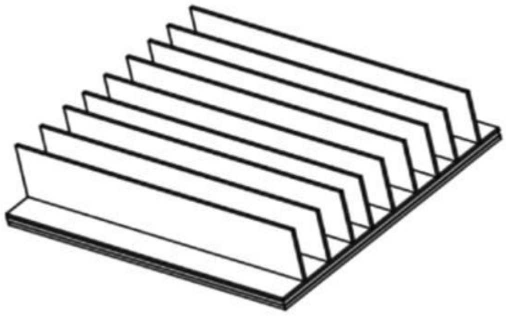

Fig. 10. - Heatsink with 20 mm fin height [56]

They looked at the effect of cooling on solar model efficiency. They tested the efficiency of PV cells using a flat cooling channel as well as a finned channel placed at the rear of the model. They discovered that the presence of fins increased the output of the model by 18.92%, and a drop in the panel temperature of 39.82 °C was recorded after it was 57.91 °C without cooling [57].

To improve thermal efficiency, a passive cooling system comprised of a heatsink with aluminum and copper fins and a number of them (5–10–15) positioned at the bottom of the panel was applied. They found that increasing the number of blades increased the thermal effectiveness of the board, with 15 blades and an aluminum base yielding the best results. Finally, the board's temperature decreased by 10.2 C, and its productivity improved by 2.74 % [48]. It is possible to enhance a solar cell's efficiency by using numerical calculations and air channels with varying airspeeds fitted with a heat sink in the shape of a hexagonal pin-fin at the bottom of the panel. Thermal efficiency increased by 60.8 percent, and electrical efficiency increased by 13.1 percent as a result [58].

3. Heatsink and PCM

The effect of PCMs on reducing the temperature increase in integrated PV cells in buildings was investigated. Two PCMs were used to mitigate the overheating of PV cells. Thermal performance was offered to improve the thermal conductivity of the PCM for different inner fin arrangements by using paraffin wax RT25 with inner fins. More than 30 °C could decrease the temperature rise of the PV/PCM system compared to a single flat aluminum sheet rest through a phase change [59]. Fig. 11 shows PCM and heatsink for cooling electronic devices.

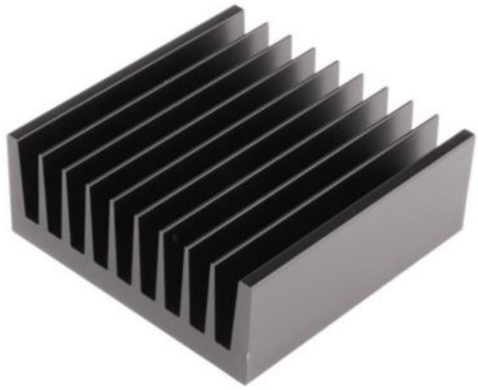

Fig. 11. - PCM with heatsink [60]

The most investigated natural cooling techniques are PCM-built, air-based, liquid-based (water and nanofluids), and radiative-based. Based on the obtained results and known technical solutions, the air-based cooling option using Alfins installed on the PV plate back surface is currently the most incredible practical passive cooling alternative, both technically and economically [61]. A 2D model of the PV layers was constructed and connected with a stage change material and heatsink to forecast the transient temperature variation. Compared to single-hole and three-hole series heatsink arrangements, heatsink geometries with three and five equivalent cavities were shown to dramatically lower panel heat. Furthermore, it was discovered that using a five-parallel-hole heatsink considerably improved the solar cell's temperature uniformity [62].

In order to enhance the photovoltaic system and make the panel work better, a container with a phase-changing material and a heatsink was made and fastened to the posterior of the panel. In order to Fig. out how deep the container should be, the effects of the environment on wind speed, melting point, and ambient temperature, as well as the depth of the fin and the distance between them, were studied [63]. A new method to improve the efficiency of solar PV panels, such as TCE, was proposed, using PCMs and aluminum panels. They used two 5 W PVs; one was combined with an aluminum plate at the rear of the panel. The panel was compared to one with a naturally ventilated plate without PCM and aluminum. It was experimentally verified that the aluminum plate at the back of the panel enhanced its efficiency by an average of 24.4%. With a decrease in average temperature of 10.35 °C, the electrical efficiency of the plate increased by 2%. The maximum decrease in temperature was 13 °C for the first day and 7.7 °C for the second day [64].

Investigated Heatsinks with fins coupled with PCM substances were produced to generate an effective heat load and improve thermal conductivity efficiency. A significant drop in temperature was seen, especially when there was a lot of heat flux [65]. The research looked at the numerical enhancement in photovoltaic cooling achieved by employing finned PCM (FPCM) heatsinks. The PV, PCM, and FPCM methodologies were tested in Southeast England's atmospheric conditions. Experience has shown that PCM heatsinks may reduce the maximum PV temperature by about 13 K, while FPCM heatsinks can enhance PV cooling by 19 K.

Fig. 12 demonstrates that PCM heat sinks may boost PV output energy from 13% to 14% [66]. They assembled and examined three distinct PCM containers, including grooved, tubed, and finned containers, to increase the output power of a PV structure (PV). The finned container proved to be the best in terms of cooling. The outcome was that the heat of the PV units dropped a lot, allowing them to produce the most electricity possible [67]. A numerical study was done to lower the temperature. Electrical devices use a mixture of phase-changing materials and heat dissipators of various shapes and sizes to raise the lousy conductivity of phase-changing materials, and a significant improvement in thermal performance was observed [68].

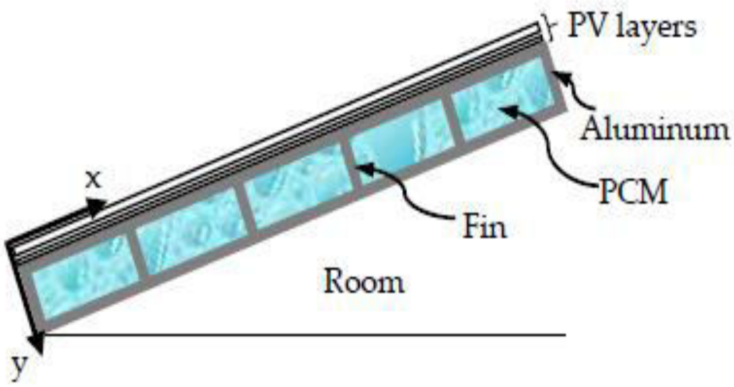

Fig. 12. - Components of the heatsink with PCM [66].

4. Cooling strategies that can boost the effectiveness of PV models

Adopting a unique micro-pipe array enhances the cooling of the solar model. Natural convection cooling devices in both air and water were evaluated. When the average radiation amount is 26.3 MJ, the most significant variations in photoelectric conversion efficiency (2.6 percent), maximum temperature drop (4.7 °C), and maximum output power (8.4 percent) are observed. When the average radiation is 21.9 MJ, the water-cooled solar plate with a heat pipe surpasses the air-cooled type by a maximum of 3% in photoelectric conversion efficiency, 8% in temperature reduction, and 13.9 percent in output power increase [69].

A new study on a hybrid solar energy system combining thermal and photovoltaic technology to cool photovoltaic cells revealed that a series of channels with only an entrance and exit were placed to the back of the photovoltaic board to ensure equal airflow distribution. In specific tests, active cooling was utilized. Temperature and efficiency are linear. The module becomes extremely hot without active cooling, limiting the solar cells' efficiency to 8–9%. When solar cells operate with active cooling, their efficiency increases to 12 and 14% [68]. Then, it worked to cool the photovoltaic panel using a wind-powered roof-top turbine blower. Solar cell cooling and ventilation were accomplished in the same process. A dynamo powered the wind turbine ventilator. To improve the productivity of the solar cell, air was circulated beneath it using a blade. Along with the ventilator's regular breathing, this combination increased the output power of the photovoltaic cell by 46.54 percent [70].

Active evaporative cooling is utilized to reduce the PV heat. The increase caused by solar irradiance absorption on PV modules was tested. He coated the rear of the panel with synthetic clay and allowed a thin layer of water to evaporate. The findings indicate that the suggested technique is technically possible, as it achieves an output voltage gain of 19.4% at its maximum and 19.1% in output energy [71]. They have created a unique method to boost the effectiveness of PV plates, which entails adding a thin layer of oil to the front side to improve the quantity of sunlight the plates receive and, consequently, their efficiency. To examine several oils, including mineral oils and natural oils. The output of the photovoltaic panel has been examined. Labovac oil lets more light through than other oils, so it has been found that covering modules with a thin film of Labovac oil, about 1 mm thick, makes the model more than 20% more efficient [72].

In Egypt, an alternative cooling method for PV panels was evaluated. Instead of a compressor, a heat exchanger uses a soil heat exchanger to cool the rear of a panel. The thermally pre-cooled airflow across the back of the panel at an ideal ratio of 0.0288 m^3/s successfully moderated the board's temperature from 55 °C (without cooling) to 42 °C. The photovoltaic panel's electrical output improved from 18.90% to 22.98% at this optimal flow rate[73]. The experiment to cool solar panels with saturated activated alumina and saline water is presented at varying radiation levels. In the 6-hour test, two irradiation levels of 800 W/m2 and 1000 W/m2 were used.

The salt influence, mainly on activated alumina tablets, was monitored for four months. Internal and exterior design changes recommended increased system cooling by 3–4 to Cover previous configurations [74]. They developed a novel cooling method that works with solar panels. The thermo-magneto-generator system operates as both a thermal dissipater and an electrical generator. The cooling technique improved efficiency by over 99%. The peak generation is 1.6 mW/m^2 [75]. A cotton fiber mesh is used to make the plate's back surface cooler; this mesh takes in water from a pipe and transmits it down the slope of the device by capillary action. During the experiment, the temperature decreased by 23.55 degrees Celsius. As a result, the panel's power increased by approximately 30.3 percent [76].

Hydrogel beads soaked with Al2O3 liquid nanofluid are used to cool solar panels. With 0.5 percent wt., the surface temperature dropped from 17.9 degrees Celsius to 17.1 degrees Celsius. From a performance standpoint, 0.5 percent wt. Provided the best results, but due to the cost of nanomaterials, 0.25 percent wt. Concentrations are the most cost-effective option [77]. A smart water spraying approach that ineffectively solves a critical gap faced by the PV cell during hot weather situations. The use of an Arduino board to implement a microcontroller temperature control water spray device improved the effectiveness of the solar cell. The study used a temperature control feedback system and made a cooling algorithm for solar collectors, which made the PV panel array about 16.65% more efficient [78].

The effectiveness of polycrystalline photovoltaic cells when cooled by evaporation was investigated. Under similar circumstances, cooled PV panels outperformed uncooled PV panels in efficiency and output. Evaporative convective cooling uses a wet cloth on the cooling channel's bottom surface. When a 120 mm air gap was used to cool the solar model, it increased daily energy output and efficiency by about 1.7 and 1.2 percent, respectively [79]. Water-based photovoltaic systems. This technology reduces the photovoltaic panels' temperature by 5–6 °C. The solar PV absorber system is perhaps the most economically advantageous from a thermal and electrical energy production standpoint. Self-contained PV systems might benefit from water evaporation on the rear of the panels by utilizing mud and cotton wicks. Solar panels in dry climates benefit from dual cooling [80].

5. Variables that influence solar cells' productivity

The impact of various reasons on the panel temperature of selected PV methods in Singapore was examined, including material, ventilation, module frame, and other ambient circumstances. The monitoring findings revealed that the temperature rose between the lowest and highest temperatures. Readings varied due to three factors. When the temperature of silicon wafer-based modules increases by one degree, power consumption decreases by 0.45% [81]. They modified initial conditions such as transparent conductors, metallic pattern conductivity, and low light intensity, allowing for grid design and finger size optimization. The results show that a metal grid with 20-lm broad lines would enhance the performance effectiveness of the solar board by 11.7% [82].

The impacts of external influences on the module's temperature were explored. The sun, wind, temperature, and distance between neighboring cells were all considered. The solar panel layer reached a maximum temperature of 331.76 kelvin. Additionally, lighter irradiation facilitates the solar module's thermal dissipation, increasing its temperature. When the wind speed goes from 0 meters per second to 1 meter per second, the efficiency of a solar module also goes up [83]. The influence of humidity on solar panel output was tested in a lab. After measuring PV output (voltages and currents), solar radiation incident studies show that solar irradiance and panel power production decline when humidity increases. The panel's output power decreases by 34.22 percent for every 50 percent increase in humidity [31].

The distance between the panels and the roof impacted the free airflow's ability to detect the panels' temperature. It was discovered that the natural airflow beneath them influenced the panels' performance. The amount of solar irradiation, distance between solar models, and so on were also investigated. The average temperature of a PV group without an air cavity is about 12 c greater than that of a PV array with an air gap of more than 200 millimeters and about 18 c higher, widened to 250 millimeters [84]. The influence of dust depletion on the electrical output of the SPV was examined, and an experimental examination of the output power sensitivity throughout dust depletion was performed. Sand storms, levels of pollution, and snow quantity all significantly influence SPV's performance. These difficulties reduce solar panel efficiency and have a detrimental influence on electrical performance [85].

Snowfall on photovoltaic panels can significantly reduce power output, as shown in Fig. 13. This effect must be precisely anticipated to be considered a reliable energy source. There were other topics they investigated. To examine both engaged and cumulative solar irradiance and the thermal capacitance of the PV panels [86]. Hand scrubbing, vacuuming, and electrostatic precipitation are some cleaning techniques used. This cleaning procedure can increase the panel's efficiency by 15-20% [87]. Then, it was found that dust reduces the sunlight the solar cells receive, lowering the output. So, cleaning routines are implemented to increase panel performance. The more frequently clean, the better; though this may require more energy, the gain may need to be increased [88].

Fig. 13. - The effect of the snow on the model [89]

Conclusion

The heat of the photovoltaic modules is a crucial aspect that determines the amount of power they will produce. While more sunlight can be beneficial, it also raises the panel's temperature, which can offset some of the benefits. In reality, the most efficient solar photovoltaic panels only transform about 20% of the incident solar irradiance into straight current energy, with the majority of the remaining irradiation being reflected or absorbed by the module material as heat [85]. When the environment's temperature rises by one degree Celsius, the panel's efficiency falls by 0.5% and its voltage falls by 2.2 mV. The high heat of the cell will harm the model's ability to produce power [90]. There is a solid motivation to decrease cell base temperature through heat transfer and removal methods in the fastest and most straightforward technique possible.

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Information of the authors

Aljumaili Ahmed, Msc., lecturer, Altinbas University
e-mail: yaser.alaiwi@altinbas.edu.tr

Alaiwi Yaser, PhD, assistance professor, Altinbas University
e-mail: yaser.alaiwi@altinbas.edu.tr

Al-Khafaji Zainab, PhD, lecturer, Imam Ja'afar Al-Sadiq University, Universiti Kebangsaan Malaysia
e-mail: p123005@siswa.ukm.edu.my